from the one used for the older mini-pleat filters in that the filter pack is mounted into the filter frame in the usual way (i.e., perpendicular to the air flow direction) rather than as a number of 20-mm-deep panels arranged inside the filter frame in a series of V-formations. A 6-in.-deep mini-pleat separatorless filter contains the same area of filter paper as the 12-in.-deep separator type. This filter has been placed into service, but there is no experience to report concerning nuclear applications.

1.1.11 DISPOSAL OF SPENT FILTERS

It often costs more to dispose of a contaminated spent filter than its initial purchase price, which reflects the difficulties associated with handling contaminated wastes and the shrinking number of authorized disposal sites. During the early years of the nuclear age (when HEPA filters were constructed with wooden frames, corrugated separators, heavy Kraft paper, cellulose-containing filter paper, and conventional rubber cement) high-temperature incineration resulted in a 99 percent reduction in bulk. This was considered at the time to be the best way to handle used filters, and a number of incinerators were constructed and used to reduce the bulk of all combustible contaminated wastes, including spent filters. However, the incinerators quickly became contaminated and proved difficult to operate and repair in a safe manner. To protect the environment, HEPA filters were installed as the final flue gas cleaning element, but they proved to have a short service life in incinerator service. Processing the spent flue gas filters through the same incinerator they were installed to serve greatly increased the burden on the incinerator, thereby reducing productive throughput and elevating costs.

During the 1960s, as a result of the introduction of noncombustible elements into the structure of HEPA filters intended for nuclear service and the introduction of heavy presses designed to crush HEPA filters into a small volume for ground burial at little cost, outmoded high-temperature volume reduction incinerators were shut down and dismantled. Where recovery of transuranic elements from spent filters remained a requirement, devices were developed to extract only the filter paper from the frame for chemical or high-temperature treatment. The remainder of the filter was disposed of by crushing and burial.

The rapidly escalating cost of land disposal for radioactive wastes, in addition to new requirements for corrosion- and leak-proof containers that substantially increase the bulk of the waste package, have combined to renew interest in the volume reduction of wood frame filters by high-temperature incineration in spite of an obvious incompatibility between a need for noncombustible filters and a wish to minimize disposal costs by high-temperature volume reduction. Exclusive use of separatorless HEPA filters helps reduce the residue from incineration. When using metal frames and corrugated aluminum separators, alternatives include punching out the filter pack into a high-pressure press for volume reduction and decontaminating the metal parts via chemical treatment. Incineration of contaminated HEPA filters continues to present formidable operating difficulties and high costs. Additional difficulties are experienced when the substances collected on filters are classified as both hazardous chemical and radioactive wastes.

1.2 DEEP-BED SAND AND GLASS FIBER FILTERS

Although HEPA filters came to dominate aerosol containment for most nuclear applications, from the beginning there were other filter innovations of note. When a high-activity level was detected at Hanford, Washington, in 1948 and traced to radioactive particles emitted from the chemical processing ventilation stacks, the chemical engineering practice of using deep beds of graded granular coke to collect mists escaping from contact sulfuric acid plants was recalled, and a number of large sand filters were constructed during the late 1940s and early 1950s at both the Hanford and Savannah River Sites.[23] The sand filters closely followed the deep-bed (100- to 300-cm-deep) graded-granule techniques for building granular filters that were widely accepted at sulfuric acid manufacturing plants and for the purification of municipal drinking water supplies. These filters had collection efficiencies for particles greater than 0.5 μm that compared favorably with the best fibrous filters then

available. They operated at a superficial face velocity of 3 cm/sec, an initial pressure drop of 2.0 kPa, and an activity reduction of 99.7 percent. Additional units were built at the Savannah River Site (SRS) later, and each has given many years of continuous service. It should be noted that the design airflow resistance of deep-bed sand (DBS) filters is higher and the retention efficiency lower than may be obtained using absolute filters, but freedom from servicing and replacement over many years are important advantages when the collected material is intensely radioactive. In addition, DBS filters are nonflammable, largely unaffected by condensed water and strong acids, and provide a substantial heat sink in the event of fire or explosion. They are, however, also large, expensive, and nondisposable.

Rapidly emerging glass fiber technology during the 1940s and 1950s shifted attention to the use of very deep beds (250 cm or more) of curly glass fibers, combined with HEPA-quality final filters, as a satisfactory substitute for sand filters when treating gaseous effluents from chemical operations.[73] These proved to be more efficient and to have lower airflow resistance than the sand filters they replaced. Deep-bed glass fiber filters have been used at Hanford for several decades on their Purex process effluent stream, and a similar installation is in place at the DOE Idaho chemical plant. In addition, an investigation was conducted to determine the ability of a similar type of deep-bed fiber filter to collect and store, at modest pressure rise, very high loadings of sodium-potassium fume that might accidentally be released from a liquid metal fast breeder reactor.[19]

There has been interest in sand filters for emergency containment venting for light-water reactors. An installed Swedish containment venting system known as FILTRA features large concrete silos filled with crushed rock. These silos were designed to condense and filter steam blown from the containment and to retain at least 99.9 percent of the core inventory.[23] Later designs for containment venting utilized wet systems to remove gaseous radioiodine.[23]

1.3 BRIEF HISTORY OF GAS ADSORPTION

1.3.1 INTRODUCTION

Iodine in its many chemical forms is probably among the most extensively studied fission products produced in the nuclear industry. The generation, release mechanism, properties, forms, trapping and retention behavior, and health effects of iodine-131 have been the subject of numerous studies, but a comprehensive understanding of the significance of its release to the environment and integration of the chemical technology into protection technology may remain incomplete in some aspects. The technology associated with the removal and retention of all iodine isotopes is similar to that for iodine-131, but interest in removal efficiency has shifted somewhat toward the importance of long-term retention with the increasing half-life of the iodine isotope.

A removal technology for the radioactive noble gases (krypton, xenon, radon) using adsorbents has also been studied extensively. This removal technology has become a standard control method for boiling water reactor (BWR) offgas decontamination and has replaced pressurized tank retention for pressurized water reactor (PWR) offgas control. A similar technology can be used to hold up the krypton-85 contained in reprocessing offgases.

Volatile metal compounds such as ruthenium and technetium can be removed from gas streams by adsorption, but a solid-surface-supported chemical reaction is often necessary for good retention. Removal technologies for carbon-14 and tritium also involve the use of adsorbents, either as collecting agents or as catalysts for conversion to other, more easily removed compounds.

Vapor recovery by adsorption was a well-established chemical engineering unit operation process prior to nuclear technology development for weapons and power production. Generally, vapor recovery systems utilized beds of activated carbon that were 60 cm deep or more and often consisted of two or more identical units in parallel so that one could be on-stream while a second was being desorbed by low-pressure steam and a possible third was undergoing cooling after steam desorption. These multi-bed arrangements made